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13. ABSTRACT *(Maximum 200 words)*

This report documents work in two areas: (1) investigate the environmental impact of shipboard paper pulper discharge in the ocean, and (2) evaluate the effectiveness of enzymes for cleaning membranes in Navy shipboard graywater systems. Field tests were conducted to measure paper pulp concentrations behind a U.S. Navy frigate using a shipboard paper pulper. These measurements helped validate a model being used by the Navy to predict wake dilution rates. For the enzyme tests, experimental protocols were developed and used to run tests on several different enzyme types to determine their cleaning effectiveness on fouled membranes used to filter graywater. Cleaning efficiences of 12 to 27% were measured. Based on these results, an enzyme mixture was designed for further testing.

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FINAL REPORT

GRANT #: N00014-95-1-1289

PRINCIPAL INVESTIGATORS: Dr. D.G. Ondercin, Dr. CC. Sarabun, Dr. R.S. Potember

INSTITUTION: Johns Hopkins University Applied Physics Laboratory

GRANT TITLE: Environmental Quality Project

AWARD PERIOD: 1 September 1995 to 31 December 1996

OBJECTIVE: This project had two separate subtasks; they will be reported as subtasks A and B through the rest of this report.

A: to investigate the environmental impact of shipboard paper pulper discharge in the ocean

B: to investigate the feasibility and effectiveness of using enzyme solutions for membrane cleaning in Navy shipboard graywater systems.

APPROACH: A: Provide support to field tests being conducted by Naval Research and Development (NRaD) to track the fate of paper pulp discharged into the ocean by shipboard paper pulpers. The paper pulper was installed aboard the U.S. Navy frigate USS *Vandergrift* (FFG-48), and the paper discharge concentrations in sea water were measured from a research vessel, R/V *Acoustic Explorer* (AX) executing a variety of maneuvers astern of the frigate. A brand of standard office copy paper was found which used a paper sizing with sufficient fluorescence to allow detection of individual paper fibers after their submersion in sea water. A towed sampling system deployed from the AX pumped sea water from three discrete depths up to the deck of the AX where the water was run through mesh filters to concentrate the paper fiber. This concentrate was then saved for subsequent analysis with fluorometers. In addition, the frigate's wake was marked by including fluorescein dye in the pulper discharge. A towed fluorometer chain with five in-fairing fluorometers was deployed from the AX and used to determine the wake geometry and the wake dilution level behind the frigate.

B: This work used one of the existing laboratory prototype units at the Carderock Dvision of the Naval Surface Warfare Center (NSWCCD), code 633. Each module contained eight, 5-foot tubular membranes in series. the membranes were Zenon UF-75 with a molecular weight cutoff of 75,000 Daltons. The system processed graywater for

approximately 10 hours daily, using a 50:1 graywater concentration (i.e. for every 50 gallons of graywater, 49 gallons leave as permeate) to produce rapid membrane fouling. Four types of individual enzymes were tested for their cleaning ability: lipase, protease, amylase and cellulase. A three step cleaning process was used. Two of the fouled membranes were flushed with freshwater, then cleaned for 8 hours by recirculating one of the enzymes, and then flushed with freshwater. One membrane was left uncleaned, but flushed with water, to serve as a control. The degree of cleaning was then determined by filtering pure water through each of the membranes.

ACCOMPLISHMENTS: A. A large-scale field test, the Shipboard Pulper Discharge Fate Test, was conducted 12 through 14 February 1996 in the local San Diego, CA, Fleet operating area. The technical objectives of the test were to:

- Collect and measure the paper pulp concentration in sea water samples at several known depths, at a series of known distances aft of a frigate that is uniformly discharging paper pulp while underway at various speeds.
- Measure the temporal and spatial extents of the dyed pulp wake of a frigate underway at various speeds.

A series of 13 data collection runs were conducted over a 3-day period. Seven runs were specifically designed to measure the concentration field of paper particles at fixed distances astern the discharging frigate, approximately 1, 5, 10 and 25 frigate shiplengths behind, when both vessels were traveling at 8 kts. The remaining data collection runs were designed to measure cross-wake dispersion of the fluorescent dye at continually increasing distances behind the frigate by crossing the frigate's wake with the AX in a series of zig-zag maneuvers. The *Vandergrift* would travel a straight course at either 8 or 15 kts during these tests.

B. As part of developing the approach described above, the current literature on enzymatic cleaning techniques, products and materials was surveyed. No product was found that could be applied directly to treat the graywater fouling problem. As a result, it was decided to purchase individual enzymes and make solution "in-house" tailored to treat graywater fouling. This approach was advantageous since it allowed the Navy to make cleaning solutions from generic enzymes and avoided the high costs associated with sole source suppliers. JHU/APL worked with the Carderock Division to design an experimental protocol to test individual enzymes or solutions of enzymes for cleaning the membrane modules being used to treat graywater. APL/JHU built, tested and delivered a 25 gallon reaction vessel to hold, possibly heat, and circulate the enzymes being tested

for cleaning. This reaction vessel was incorporated into the NSWCCD test facility for the actual cleaning tests. Tests were run on the four individual enzyme classes: lipase, protease, amylase and cellulase.

CONCLUSIONS: A. Key results of the pulper field test were:

- The test successfully provided the data required to evaluate the near-term fate of pulp discharged into the ocean from a frigate. Analysis of the data showed good results between NRaD model calculations and the test measurements.
- A detailed description of the spatial evolution of the dyed wake pulp was obtained for the first 4 km of the wake at frigate speeds of 8 and 25 kts. The dyed pulp wake was highly heterogeneous, with discrete high-concentration patches embedded within a continuous meandering wake.
- The wake near the frigate was about 10 m and reached a depth >7.5 m by about 500 m aft of the frigate. The width and depth of the wake increased to almost 40 m wide near the surface and 10 m deep by 3000 m aft of the frigate.
- Good agreement was achieved between NRaD model predictions and measured minimum dilution rate estimates for both dye and pulp.
- The data suggest that in the first 2 km of the wake, the wake advection and turbulence influences, not particle settling, were primarily responsible for pulp movement in the water column.

B. The cleaning tests showed there was an increase in membrane permeability for each of the enzymes tested. The greatest effects occurred for protease, amylase and lipase, with 12-27% increases in average permeability. Based on these results, two enzyme mixtures were designed for testing in the next year. The two mixtures were (1) a mixture of equal parts of lipase, amylase, protease and cellulase, and (2) a combination of this mixture and a surfactant.

SIGNIFICANCE: A. These pulper measurements helped substantiate the NRaD conclusions that the discharge of paper and cardboard as proposed from the shipboard paper pulper will have no significant environmental consequences on a local, regional, or basin-wide scale in Special Areas designated by MARPOL 73/78 regulations.

B. The significance of this enzyme work is that onboard cleaning of graywater membranes appears possible, which will help the Navy develop a systems-level approach for achieving a zero-discharge ship to meet environmental restrictions.

PATENT INFORMATION: None

AWARD INFORMATION: None

PUBLICATIONS:

A. *Shipboard Pulper Discharge Fate Test*, D.G. Ondercin and C.C. Sarabun, Johns Hopkins University Applied Physics Laboratory report STD-R-2610, December 1996

B. *1996 Final Report for the ONR/NAVSEA Enzymatic Cleaning Program*, R.S. Potember, Johns Hopkins University Applied Physics Laboratory, December 1996